

A Transmit Power Control Proposal for IEEE 802.11 Cellular Networks

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Abstract- Actually, the idea of designing an outdoor cellular network based on WLAN IEEE 802.11 results very attractive, due to the several advantages that this technology presents. It offers the equipment at a lower cost, operates in unlicensed spectrum and allows higher data rates.

If we realize a comparison of the system performance between a cellular environment and an isolated single cell scenario we observe that the first situation exhibits a considerable decrease, due to co-channel interference, that rises with the growth of the transmission data rate employed.

In this paper, we propose a power control mechanism, as a method to reduce the interference influence on network performance, and to homogenize the behavior of the different stations in the system. We present its performance under different load conditions and compare this behavior with the original case, without the employment of any power control mechanism.

Index Terms—Cellular networks, power control, IEEE 802.11, WLAN.

I. INTRODUCTION

Wireless Local Area Networks (WLAN) are being extensively deployed in many areas. Networks that span large buildings or campuses must comprise multiple cells. Cell layout, cell coverage and channel allocation are some of the problems that must be addressed together, and finding an optimal solution is a complex task to achieve. Due to the small number of available channels in the public 2.4 GHz band, co-channel and adjacent channel interferences are significant issues [1]. Moreover, it can be shown that in such multicell networks, typically, the coverage ranges of co-channel cells overlap, what adds the overlapping *Basic Service Set* (BSS) problem to transmission errors. The overlapping BSS problem refers to situations where stations belonging to different co-channel cells are in the coverage range of each other: these hosts are called *exposed terminals*. This fact results in an important problem that leads to considerable degradation in network performance, what has been evaluated recently [2].

On the other hand, the idea of designing an outdoor cellular network based on WLAN IEEE 802.11 results very attractive. IEEE 802.11 presents several advantages in front of 2.5G and 3G wireless networks, due to the low cost of the equipment required and its operation in unlicensed spectrum. Furthermore, IEEE 802.11 offers higher data rates, far exceeding the maximum data rates offered by *Enhanced Data Rates for GSM Evolution* (EDGE) and *Wideband Code Division Multiple Access* (WCDMA) networks.

Surprisingly, the multicell scenarios have received little attention in literature, because usually the performance of wireless LANs is evaluated assuming one isolated single cell.

Having these considerations in mind, in [1] we have evaluated the IEEE 802.11 network performance in a cellular environment. We have presented its performance under different load conditions and compared these results with the obtained in a single cell environment. In this way, we have determined that for higher data rates the system throughput performance decreases considerably due to co-channel interference. Furthermore, each station performance depends strongly of its relative position to its access point (AP). Thereby, the throughput performance becomes poorer with the distance increase.

Going a step further, the focus of this paper is to propose a power control mechanism to reduce the interference influence on network performance, to homogenize the behavior of the different stations, and to assimilate their performance to the observed in a single cell environment.

Several power control schemes for IEEE 802.11 networks have been proposed in the literature. In mobile ad-hoc networks, some power control protocols have been presented. Their main objectives have been centered in the improvement of energy consumption [3], and in the creation of the connectivity set to improve system throughput performance [4] – [7].

Furthermore, in infrastructure networks some studies have been carried out. Reference [8] presents power measurements on current IEEE 802.11b network cards and characterizes the influence of bit-rate, transmit power and frame size on total power consumption. In [9] a transmit power control mechanism is presented to save energy in wireless devices.

In contrast to the studies quoted in previous paragraphs, in this paper we analyze the suitability of a power control mechanism, with the objectives of mitigating the interference influence on IEEE 802.11 cellular network performance and of homogenizing the behavior of the different stations.

The organization of the rest of the paper is as follows: section II presents the main topics of the IEEE 802.11 MAC working procedure, section III describes the simulation environment, section IV presents the power control proposal, section V exposes the main results of IEEE 802.11 cellular network performance employing this mechanism. Finally section VI concludes with the most relevant points of the paper.

II. IEEE 802.11 MAC PROTOCOL

IEEE 802.11 presents two operating modes: *Distributed Coordination Function* (DCF) and *Point Coordination Function* (PCF). The most common working mode is DCF, which employs the medium access control (MAC) algorithm called *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA). It works as follows: before initiating a transmission, a station senses the channel to determine whether it is busy. If the medium is sensed idle during a period of time called *Distributed Interframe Space* (DIFS), the station is allowed to transmit. If the medium is sensed busy, the transmission is delayed until the channel becomes idle again. A slotted binary exponential backoff interval is uniformly chosen in $[0, CW-1]$, where CW is the contention window. The backoff timer decreases as long as the channel is sensed idle, stops when a transmission is in progress, and is reactivated when the channel is sensed idle again for longer than the DIFS. When the backoff timer expires, the station attempts transmission. After each data frame is successfully received, the receiver transmits an acknowledgment frame (ACK) after a *Short Interframe Space* (SIFS) period. The value of CW is set to its minimum value, CW_{\min} , in the first transmission attempt, and ascends in integer powers of 2 at each retransmission, up to a pre-determined value.

The IEEE 802.11 MAC protocol supports two kinds of BSS: the independent BSS, known as ad-hoc networks, which have no connection to wired networks, and the infrastructure BSS, which contains an AP connected to the wired network. The second BSS assimilates to cellular networks with base stations. In this way, we restrict our investigation to infrastructure networks operating in DCF mode.

III. SIMULATION ENVIRONMENT DESCRIPTION

We have chosen the physical layer of the IEEE 802.11g for this study. To analyze the IEEE 802.11g performance, we use a simulation tool implemented in UPC (Technical University of Catalonia). Our simulation program, written in C++ programming language, follows all the IEEE 802.11 protocol details. It emulates as closely as possible the real operation of each transmitting station. Our simulation tool permits the IEEE 802.11 protocol emulation in a single cell environment and in a cellular network. On the contrary, we have observed that the well-known NS-2 Simulator presents some flaws in a cellular scenario. In this way, we choose the exposed simulation tool to study the cellular network performance.

The simulation tool permits the evaluation of different parameters: throughput (user data correctly transmitted by users without considering retransmissions and headers), average transmission delay, average queue delay, probability of collision, *frame error ratio* (FER) and *signal to noise and interference ratio* (SIR). The simulation tool has been verified comparing the results obtained with the information published in [10], under identical simulation conditions.

The values of the parameters used to obtain the numerical results are exposed in Table I.

The simulation environment consists of 100 hexagonal cells, which form a rectangular area, and only the 36 middle cells are considered to compute the statistics. Each BSS is composed of 1 AP and 10 user stations, which are distributed randomly following a uniform distribution throughout the cell area. All cells have the stations distributed at the same positions, which are static. We take into account different load situations as in [11]. First, we consider that data frames are directed only from user stations towards the AP, which forwards them to the infrastructure network. Subsequently, we evaluate the system when AP and user stations are transmitting data frames. In this case, we distinguish between a *symmetric* and an *asymmetric* traffic load distribution. We consider symmetric traffic load conditions when all stations (AP and user stations) present the same traffic load. On the other hand, when the traffic load at the AP is much heavier than that at user stations, the system is operating under asymmetric traffic load conditions. Data frames have a constant payload size of 1023 bytes and the time between consecutive arrivals follows an exponential distribution function. The simulation time employed is large enough, so that we achieve the convergence of the power control algorithm.

As path loss model we employ the validated propagation model for IEEE 802.11 devices operating at 2.4 GHz in outdoor environments specified in [12]. This model follows the next path loss equation:

$$ploss(dB) = 7.6 + 40 \log_{10} d - 20 \log_{10} h_t h_r, \quad (1)$$

where d is the distance between stations and h_t , h_r the antenna heights for transmission and reception.

The OFDM has been selected as the modulation scheme for the IEEE 802.11g Extended Rate PHY (ERP-OFDM). It is identical to the modulation scheme employed in the previous IEEE 802.11a PHY, which is very similar to the one chosen in Europe for HIPERLAN/2 PHY. It offers eight PHY modes with different modulation schemes and coding rates; therefore data rates between 6 and 54 Mbps are provided.

In this paper we assume that the noise over the wireless medium is white Gaussian noise (AWGN). The bit error probability (P_b) depends on the modulation scheme employed.

The bit error probability [13] for an M -ary QAM modulation with a Gray coding and $M = 4, 16$, and 64 is calculated by:

$$P_b^{(M)} \approx \frac{1}{\log_2 M} (1 - (1 - P_{\sqrt{M}})^2), \quad (2)$$

where

$$P_{\sqrt{M}} = 2 \left(1 - \frac{1}{\sqrt{M}} \right) Q \left(\sqrt{\frac{3}{M-1} \left(\frac{E}{N_o} \right)} \right). \quad (3)$$

$P_{\sqrt{M}}$ is the symbol error probability for the \sqrt{M} -ary PAM modulation with the average signal-to-noise ratio per

symbol $\frac{\bar{E}}{N_o}$.

For BPSK modulation, the bit error probability is the same as the symbol error probability:

$$P_b^{(2)} = Q\left(\sqrt{2\left(\frac{\bar{E}}{N_o}\right)}\right). \quad (4)$$

In [14], an upper bound was given on the FER , under the assumption of binary convolutional coding and hard-decision Viterbi decoding with independent errors at the channel input. The FER is obtained following (5):

$$FER = 1 - (1 - P_u)^{\text{bits per interval}}. \quad (5)$$

The P_u value depends on the PHY mode employed: on its modulation scheme (that is on $P_b^{(M)}$) and on its coding rate. The detailed calculation of P_u is specified in [15].

To decide if a frame is received with error at reception time, it is split up in intervals, where the interference power has different values. For each frame interval the SIR is obtained and its correspondent P_u computed.

Then, to decide if a frame is erroneous, for each frame interval, a random value between 0 and 1 is calculated. If this value is lower than the FER value, the frame is considered erroneous; otherwise this interval is considered successful and the next one is evaluated in the same way.

IV. TRANSMIT POWER CONTROL PROPOSAL

As presented in [1], the throughput performance in a cellular network decreases considerably for higher transmission data rates, due to the influence of co-channel interfering frames. Furthermore, data frames generated at stations placed near the limit of the coverage area arrive at its AP with lower power level, and obtain an important SIR decrease. In this way, the throughput performance becomes poorer as the stations increase their distance from their AP.

Thereby, we propose the employment of a power control mechanism to mitigate the interference influence on network performance and to homogenize the behavior of the different stations, independently of their distance from their AP. For our study, we consider that all the stations in the system are working at the same data rate.

Actually, WLAN cards change their transmission rate in relation to the SIR observed. In this way, if a station obtains low throughput performance, it will decrease its transmission rate. This mechanism is known as *link adaptation scheme*.

Therefore, with the employment of a power control mechanism we pretend to improve the SIR performance of the farthest stations, so that a change in the transmission rate is not necessary. In this way, stations will be able to work at higher transmission rates, and we will avoid the *performance anomaly* that appears in WLANs with hosts operating at different rates: the rate of a slower host limits the throughput of a fast host [16].

TABLE I
MAIN PARAMETERS USED IN THE SIMULATIONS

	802.11g (ERP-OFDM)
Transmission data rate (Mbps)	6, 9, 12, 18, 24, 36, 48, 54
MAC header	34 bytes
PHY Preamble	16 μ s
PHY Header	4 μ s
Slot Time	9 μ s
SIFS	10 μ s
DIFS	28 μ s
Minimum backoff window size	16
Maximum backoff window size	1024
OFDM symbol interval	4 μ s
Cell radius	200 m
Initial tx power level output	30 dBm
Noise power	-96 dBm

There are different mechanisms to implement power control, from the simplest one that consists on regulating manually the transmit power using the configuration software that most IEEE 802.11 hardware devices provide, to the most complicated one that would take into account the SIR measures and would define new IEEE 802.11 control messages.

Our proposal does not intent to modify or implement new control messages for the IEEE 802.11 standard. In this way, it can be easily included in the configuration software provided by the IEEE 802.11 hardware devices.

We propose a closed-loop method, which follows the working procedure specified subsequently. This power control is based on the algorithms proposed for the third-generation WCDMA system [17]. Our proposal works as follows.

Initially, all stations are transmitting data frames at the maximum power level of 30dBm. After each ACK successfully received, the station decreases its transmit power level by a value called step Δ . Furthermore, every time that the retransmission timeout expires at the transmitter, its power level is increased by Δ . Remember that a station is not allowed to transmit at a power level higher than 30dBm. To achieve a faster convergence of the algorithm, we propose to employ an adaptive step. The step value adapts itself to the transmit power adjustment needed, avoiding, in this way, instability. In this case, the step is multiplied by α , when n_l consecutive successfully ACKs are received, or when the retransmission timeout expires n_l consecutive times. Finally, the step is divided by β , if the transmitter alternates between an ACK successfully reception and a retransmission timeout expiration. To perform our study, we consider $\Delta=1$ dB, $\alpha = 1.5$, $\beta = 1.5$ and $n_l = 2$. With these parameters choice we achieve a faster convergence. We have evaluated the power control mechanism working with other parameter values, and we

have observed that the results are not better but the instability becomes higher.

Due to the employment of power control mechanisms, the IEEE 802.11 performance may be degraded, because of the appearance of the hidden terminal problem. To solve this additional problem, we decide to employ the RTS/CTS working mechanism for the power control method proposed. In this way, RTS and CTS frames are always transmitted at maximum power level, and the hidden terminal problem is solved. On the other hand, note that a station transmits always data and ACK frames at the same power level.

Finally, the *downlink* is more complicated to implement, in relation to the *uplink*. In this case, the AP should change the transmitting power dynamically according to the user station to which it forwards its data.

V. SYSTEM BEHAVIOR

We present the system performance under different load conditions per cell to evaluate the IEEE 802.11g cellular network behavior operating under the power control mechanism proposed. Furthermore, we compare its performance with the results obtained in a cellular environment working without any power control mechanism. Without a loss of generality, we employ a transmission data rate of 48 Mbps. The offered load per cell is presented as the normalized offered load for that transmission rate, in this case 48 Mbps. Moreover, note that the normalized saturation throughput for a single cell system operating at 48 Mbps is 0.48, and for 54 Mbps it takes a value of 0.45 [1]. In this way, for our study, we consider normalized offered loads per cell (OL) of 0.3 and 0.4.

To cellularize the coverage area we use a *Fixed Channel Assignment* (FCA) scheme with a cluster size of three cells. We assign channels 1, 6 and 11 of the 2.4 GHz band, which do not overlap between them.

Initially, we evaluate the system performance when data frames are directed only from user stations towards the AP.

Frames generated at user stations placed near the limit of the coverage area, arrive at its AP with lower power level. As can be observed in Fig. 1, the average *SIR* value at AP for frames (RTS and data frames) generated at user stations placed at different distance from their AP, decreases with the growth of this distance. Remember that the RTS frames are always sent at maximum power level. Employing the power control mechanism explained in the previous section, the most distant stations improve their average *SIR* in relation to the original network situation, as a consequence of the interference level reduction. On the other hand, the closer stations decrease their average *SIR*, due to the important reduction in the data frames transmit power.

Employing the power control mechanism proposed, the APs continue transmitting at maximum power, whereas the other stations have decreased their output power level. APs are not transmitting data frames, in this way no power control algorithm is being applied at APs. Consequently, the ACK frames generated at each AP are received at the different stations with different power level, depending on the distance between the station and its AP, and, in this way, the average *SIR* at the stations decreases with the rise of the distance (see Fig. 2). Remember that CTS frames are always

transmitted at maximum power, as explained in previous section. The average *SIR* becomes higher in relation to the results obtained under the original network situation, due to the reduction in the overall interfering power level achieved with the use of the power control mechanism.

Next, we evaluate this closed-loop proposal when stations are allowed to transmit data and ACK frames at a transmit power higher than 30dBm. Initially, all stations are transmitting data and ACK frames at a power level of 30dBm; but they are allowed to increase this power up to 33dBm. On the other hand RTS and CTS frames are always sent at a maximum power of 30dBm.

In this way, in Fig. 3 and 4 we present the throughput performance for the stations placed at different distance from their AP, under various load conditions per cell. We compare the results obtained when stations are allowed to transmit up to a maximum power of 30dBm and when they are able to rise it up to 33dBm. As presented in [1], when network load increases, the throughput performance for the different stations of a cellular network decreases considerably with the growth of the distance from their AP. With the use of a power control mechanism, the interference level decreases and the average *SIR* at AP and at stations increases for the most distant stations. Transmit power can be decreased up to 0dBm, which is the minimum transmit power fixed by the standard. In this way, the nearest station, which is placed at 15m from the AP, decreases its transmit power to the minimum value, and it still maintains its throughput as high as in the original case. Employing the power control proposal, we achieve a considerable decrease in the interference level. When stations are allowed to transmit up to 30dBm the decrease in the interference level is insufficient to obtain a considerable improvement in the throughput performance of the most distant stations, as can be observed in Fig. 3 and 4. On the other hand, results show that the increase in the maximum transmit power up to 33 dBm achieves an improvement in the throughput performance of the most distant stations. Moreover, the performance of the closest stations only decreases slightly, in comparison with the case employing 30dBm as maximum transmit power. In this way, adding this modification to the closed-loop power control algorithm we achieve a better overall system performance.

Employing the power control mechanism, we observe the decrease of the interference level, and, thus, the reduction of the *FER* in frame transmissions. In this way, the most distant stations reduce the fraction of time spent in the backoff state and consequently increase their access probability. These distant stations are in the coverage area of nodes belonging to other co-channel cells, and their transmissions provoke the accentuation of the *exposed terminals* problem. This fact explains the performance of the stations closer to their AP. The oscillations that can be observed in Fig. 3 and 4 are due to the number of stations that are affecting these *exposed nodes*.

Only the most distant stations need to increase their transmit power to the maximum value of 33dBm. And the RTS and CTS frames are sent at a maximum power of 30dBm. Thus, with the modification exposed, we still achieve an important interference level reduction, in front of the case without any power control. However, the increase

of the maximum power to higher values and the transmission of RTS and CTS frames at a higher power level will lead to greater interference level, to accentuate the overlapping BSS problem, and, in this way, to lower system performance.

Subsequently, we evaluate the power control mechanisms proposed employing a cluster size of four cells. In this case, four partially overlapped frequencies are being used (channels 1, 4, 8 and 11), with adjacent-channel interference factors presented in [18], due to the fact that at 2.4 GHz only three non-overlapped channels can be employed. With this cluster configuration, the overlapping BSS problem is being reduced.

In Fig. 5 and 6 we present the throughput performance per station for different load conditions per cell. With the employment of a cluster size of four cells together with the power control mechanism, we achieve a higher interference power level reduction, and, in this way, the throughput performance obtained is better than the observed by a cluster size of three cells, especially when a maximum transmit power for data and ACK frames of 33dBm is employed.

Note that employing this power control mechanism, we homogenize the performance of the different stations. The closer stations reduce their throughput in comparison with the original case, due to an important decrease in the data transmit power. In this way, the most distant stations achieve an important throughput improvement, due to the interference level reduction obtained.

Subsequently, we evaluate the system when APs and user stations are transmitting data frames, and the system is operating under symmetric traffic load conditions (each AP transmits as much traffic as any of the other 10 user stations per cell). Fig. 7 and 8 present the throughput performance per user station for different load conditions per cell, and for a cluster size of four cells. Fig. 9 and 10 show the throughput performance for the AP. The traffic transmitted by each AP is equally distributed between the 10 user stations per cell. For example, for 0.3 of normalized offered load per cell, the AP and each user station transmit $0.3/11=0.027$, and the AP directs $0.027/10=0.0027$ to each user station.

Results show that the power control mechanism proposed increases the performance of the most distant stations (see Fig. 7 and 8), and of the different traffic sources directed from the AP to the most distant user stations (see Fig. 9 and 10), especially when a maximum transmit power for data and ACK frames of 33dBm is employed. In this way, the power control mechanism homogenizes the performance of the different stations.

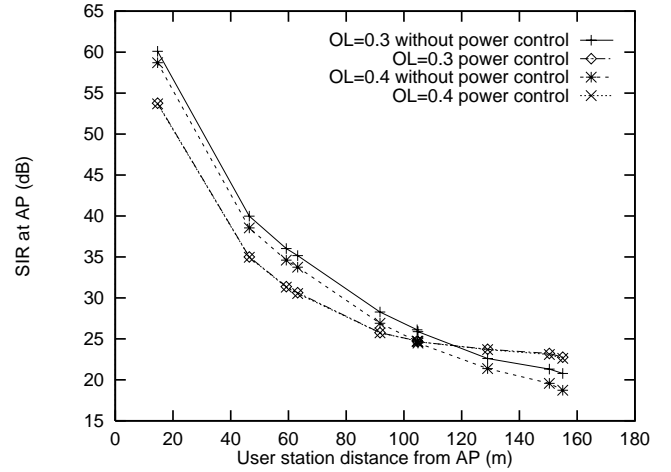


Fig. 1. SIR at AP vs. station distance from its AP, for a cluster of 3 cells

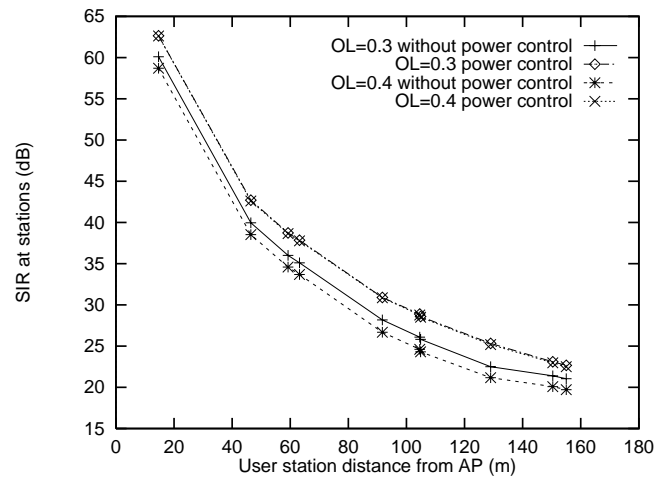


Fig. 2. SIR at stations vs. station distance from its AP, for a cluster of 3 cells

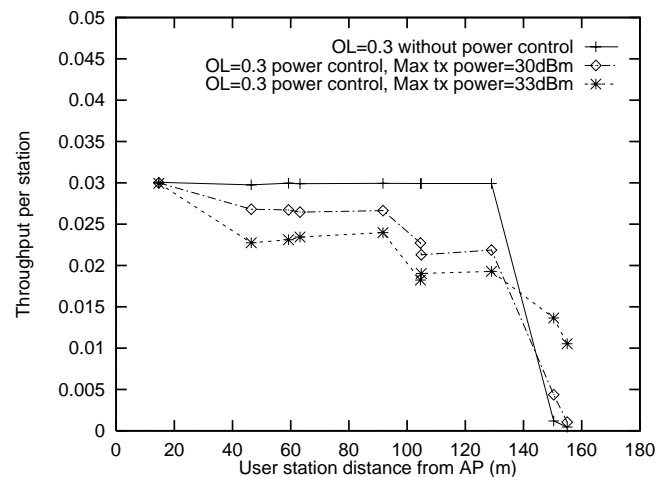


Fig. 3. Throughput per station vs. station distance from its AP, for a cluster of 3 cells and offered load per cell of 0.3

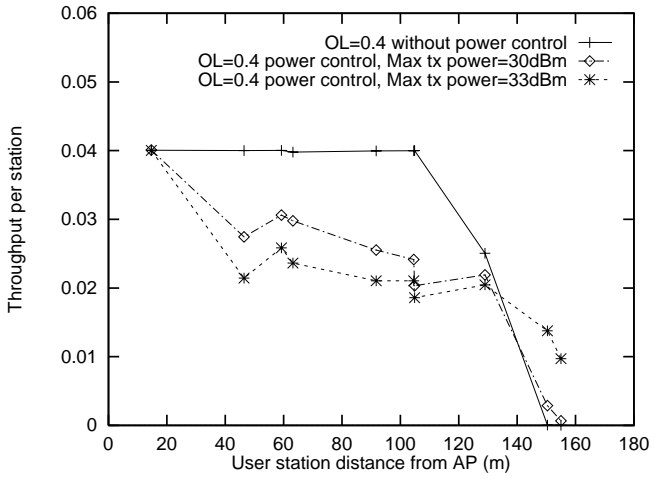


Fig. 4. Throughput per station vs. station distance from its AP, for a cluster of 3 cells and offered load per cell of 0.4

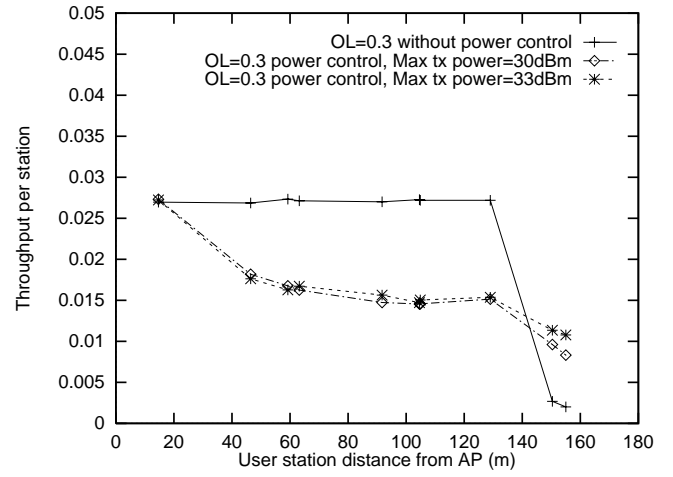


Fig. 7. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and symmetric offered load per cell of 0.3

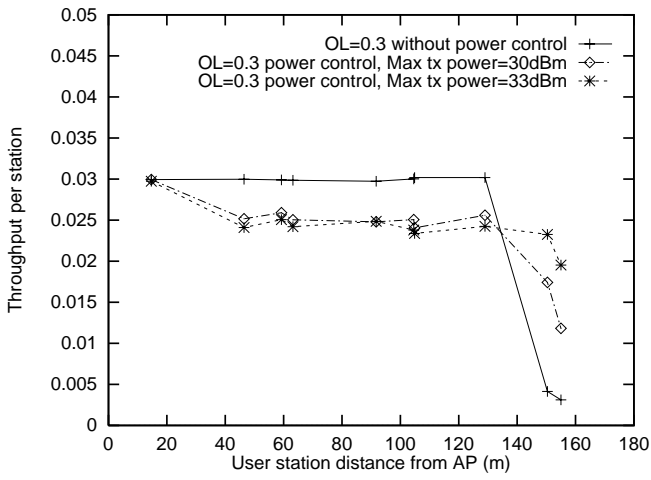


Fig. 5. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and offered load per cell of 0.3

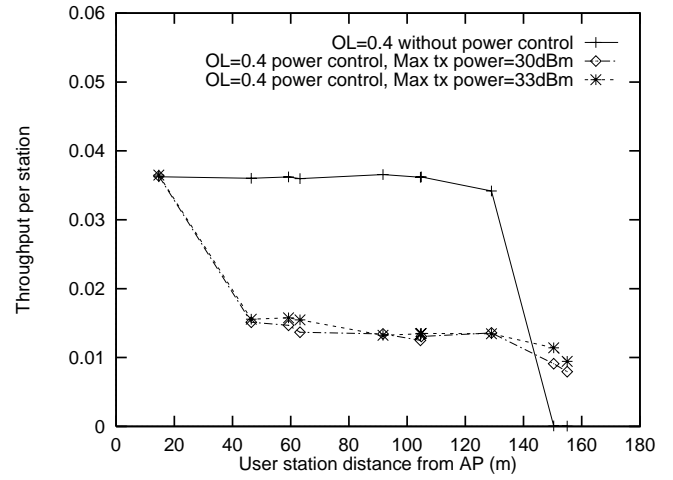


Fig. 8. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and symmetric offered load per cell of 0.4

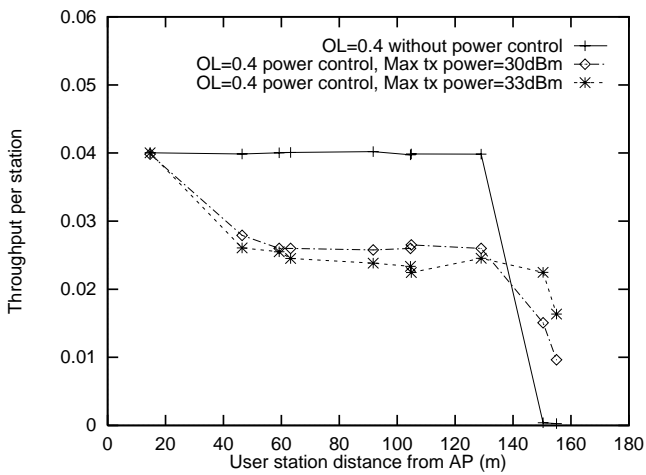


Fig. 6. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and offered load per cell of 0.4

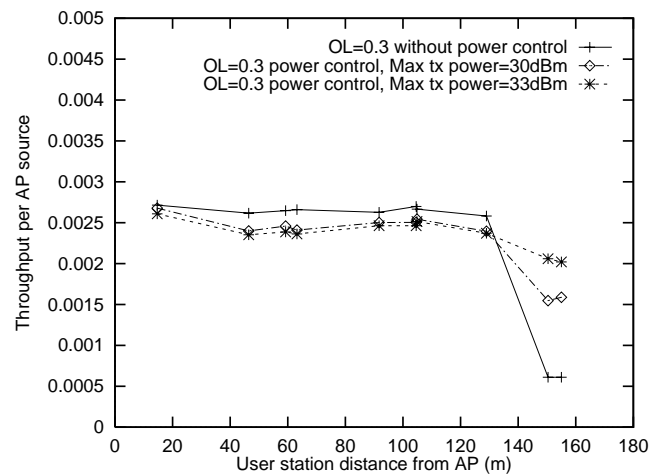


Fig. 9. Throughput per AP source vs. station distance from its AP, for a cluster of 4 cells and symmetric offered load per cell of 0.3

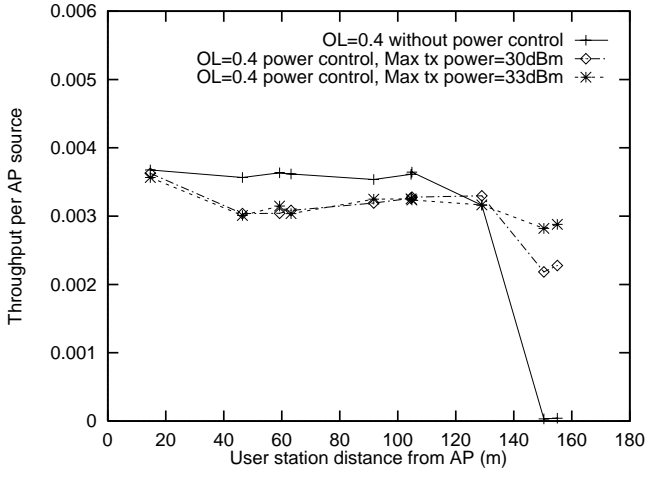


Fig. 10. Throughput per AP source vs. station distance from its AP, for a cluster of 4 cells and symmetric offered load per cell of 0.4

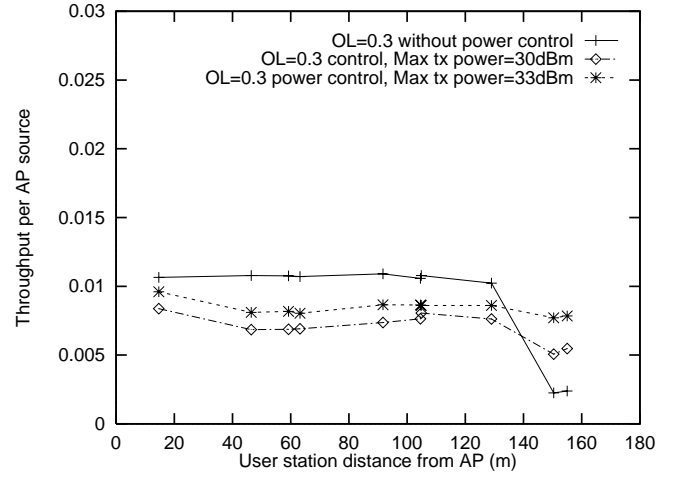


Fig. 13. Throughput per AP source vs. station distance from its AP, for a cluster of 4 cells and asymmetric offered load per cell of 0.3

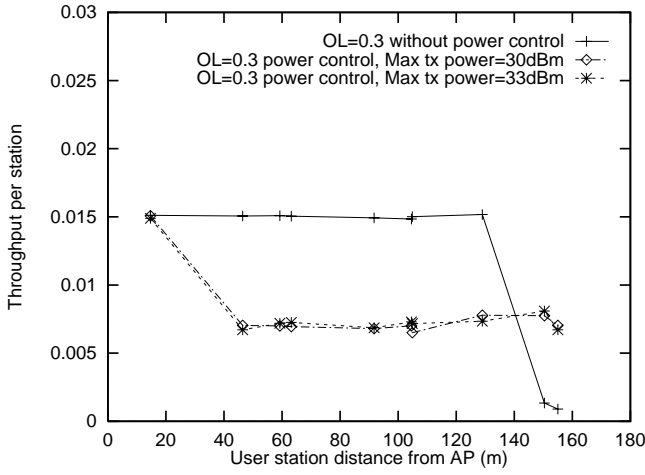


Fig. 11. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and asymmetric offered load per cell of 0.3

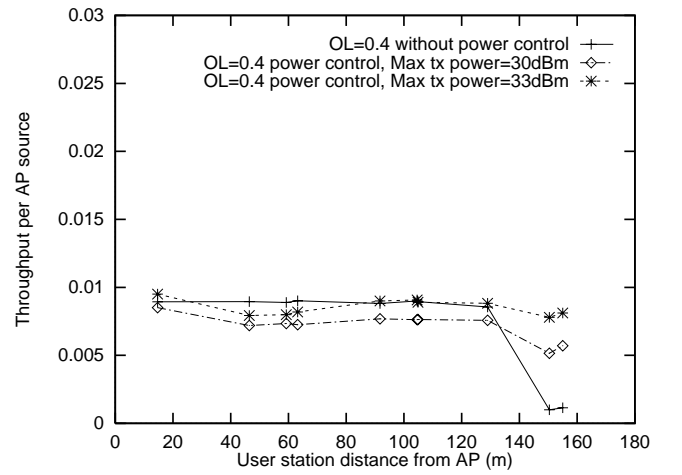


Fig. 14. Throughput per AP source vs. station distance from its AP, for a cluster of 4 cells and asymmetric offered load per cell of 0.4

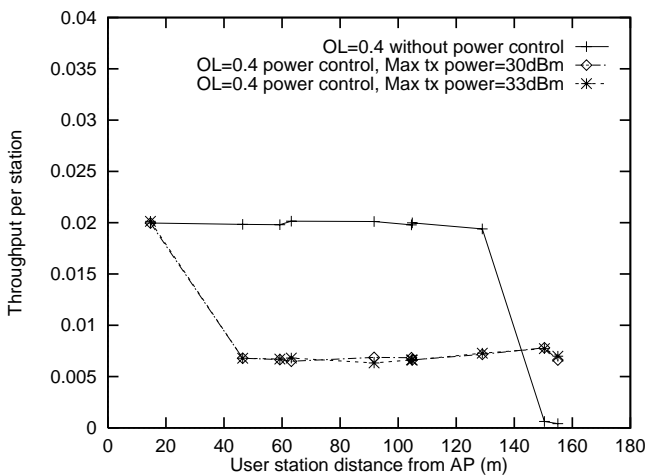


Fig. 12. Throughput per station vs. station distance from its AP, for a cluster of 4 cells and asymmetric offered load per cell of 0.4

Finally, we evaluate the system performance when APs and user stations are transmitting data frames, and the system is operating under asymmetric traffic load conditions (the traffic load per cell at each AP is much heavier than that at user stations). Fig. 11 and 12 present the throughput performance per user station for different load conditions per cell, and for a cluster size of four cells. Fig. 13 and 14 show the throughput performance for the different traffic sources directed from the AP to the various user stations. The traffic sent by each AP is equally distributed between the 10 user stations per cell and the traffic load at the AP is much heavier than that at user stations. We consider each AP transmitting the same amount of traffic than the user stations per cell altogether. Taking an example, this means that for a normalized offered load per cell of 0.3, the AP offers 0.15 (and each AP source $0.15/10=0.015$), and user stations offer $0.15/10=0.015$ each one.

Results show that the power control mechanism proposed increases the performance of the most distant stations (see Fig. 11 and 12), and of the AP sources transmitting data frames to the most distant user stations (see Fig. 13 and 14).

Moreover, the AP sources achieve an important improvement in their behavior when a maximum transmit power for data and ACK frames of 33dBm is employed (see Fig. 13 and 14). Note that the AP performance observed in both figures is similar, because, in this case, the APs are working under saturation load conditions.

VI. CONCLUSIONS

The idea of designing a cellular network becomes very attractive, due to the several advantages offered by IEEE 802.11 networks. However, as we have presented in a previous study [1], the system performance in a cellular environment decreases in relation to its behavior in a single cell scenario, because of the presence of co-channel interfering frames.

Thereby, in this paper we present a power control mechanism to mitigate the interference influence on network performance and to homogenize the behavior of the different stations. Moreover, a higher reduction in the interference level will allow stations to work at higher data rates what avoids the performance anomaly problem.

The power control algorithm proposed achieves an important interference power reduction. WLAN IEEE 802.11 networks are working at unlicensed spectrum. Other systems are allowed to work at the same frequency band; in this way, it is important to maintain the interference power as low as possible. The administrations of the different countries manage this spectrum, and its regulation can be different for each of them. Besides, in some countries a transmit power control mechanism is demanded to allow the employment of the IEEE 802.11 technology in outdoors environments.

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